SYNTHESIS AND CHARACTERIZATION OF COBALT AND COPPER DOPED NiO THIN FILMS PREPARED BY SILAR METHOD

A Synopsis submitted

To

Swami Ramanand Teerth Marathwada University, Nanded

for the degree of

Doctor of Philosophy in Physics

Submitted by

Mr. Maruti Baliram Kumbhar

(M.Sc., B.Ed., PET, MH-SET)

Email Id : mbk_physics@yahoo.com

Mob No. +919527396907

Category: OBC

Under Guidance of

Dr. Prakash M. Kulal

(M.Sc., Ph.D.)

Research Guide, Assistant Professor

Shivaji Mahavidyalaya, Renapur Dist. Latur-413527

Email Id: pmkulal@gmail.com

Mob No: +917798032739

Thin Film and Material Science Physics Research Laboratory

Dayanand Science College, Latur

2022

Abstract of proposed work plan/problem:

In the present research work undoped NiO, Co & Cu doped thin films will be deposited onto Glass Substrate and steel substrate from nickel nitrate [$Ni(NO_3)_2$] or nickel nitrate hex hydrate [$Ni(NO3)_26H_2O$] in ammonium hydroxide (NH_4OH), Cobalt nitrate $Co(NO_3)_2 \cdot 6H_2O$ and copper acetate [C_4H_6 $CuO_4.H_2O$] by successive ionic layer adsorption and reaction (SILAR) Technique. Structural, morphological, compositional, optical, and electrical properties of the NiO thin films will be studied by using XRD, SEM, FESEM, EDAX, UV–VIS spectroscopy, FTIR, DC electrical conductivity measurement. The electrochemical measurements such as cyclic voltammograms, galvanostatic charge/discharge and electrochemical impedance spectroscopy measurements will be carried out to study the supercapacitor and gas sensing performance of the undoped NiO, Co & Cu doped NiO thin films.

1. Introduction:

The recent days in multifunction portable electronic equipment and the increasing need for wireless sensor network for the developing sufficiently compact and flexible energy storage. Designing efficient, miniaturized energy storage devices, that can achieve high energy delivery or harvesting at high discharge rates with a long life time with cost effective is important. There are various energy storage devices like batteries, fuel cells and supercapacitors. There are certain limitations for batteries and fuel cells such as inflexibility, relative low power density and shorter life time. To overcome these limitations supercapacitors are attracting energy storage devices. In which electrical energy is mainly stored by fast and reversible redox reactions or phase changes on surface or subsurface of electrodes executing high power density, fast rate of charge-discharge, good cycle stability, light weight, broad working temperature range and higher life time. The transition metal oxides are recognized as the best electrode materials for supercapacitor due to faradaic redox reactions occurring at electrode surface which enhances the specific capacitance.

In present study undoped Nickel Oxide (NiO), Co & Cu doped NiO thin films will be deposited by using successive ionic layer adsorption and reaction (SILAR) Technique. The various film properties, like crystal structure, morphology, optical, electrical and electrochemical properties will be studied. The results obtained will be compared and discussed.

2. Review of Literature and Development in the Subject (Previous work done in the relevant area):

Supercapacitors also known as electrochemical capacitors or Ultra capacitors possess high energy density than a conventional capacitors and high power density than batteries. In supercapacitor charge separation takes place across a very small distance and increased surface area of electrode created by large number of pores within a high surface area electrode material [1]. It fills the gap between conventional capacitors and batteries. B.E. Conway [2] has worked for more than 50 years in the area of electrochemistry particularly interfacial electrochemistry. He was the first to realize the potentialities of some materials for their double layer energy. The capacitance of a device mainly depends on the characteristic of electrode materials particularly surface area and pore size distribution. The required electrode properties of supercapacitor electrode material arise from a combination of chemical and physical properties with high conductivity, high surface area, good corrosion resistance, high temperature stability, controlled pore structure, processability and compatibility and relatively low cost.

Yunus Akaltun et al. reported that, the effect of film thickness on the structural, morphological, optical and electrical properties of NiO thin films. The X-ray diffraction (XRD) and scanning electron microscopy (SEM) studies showed that all the films exhibit polycrystalline structure are covered well with glass substrates. The crystalline and surface properties of the films improved with increasing film thickness. The energy band gap values were decreased from 3.71 to 3.67 eV depending on the film thickness. The refractive index (n), optical static (ε_0) and high frequency dielectric constant (ε_∞) values were calculated by using the energy band gap values as a function of the film thickness. The resistivity of the films varied between 4.1 and 802.1 X cm with increasing film thickness at room temperature [3]. Nickel Oxide (NiO) has been recognized as an important material for electrochemical applications in well adherent and porous nano-like structure. This type of porous morphology provides more electroactive sites for electrolyte ions hence provide essay access for ions to electrode/electrolyte interface, which is important for the faradic redox type reaction [4]. Lokhande et al. [5] has investigated that the impact of ratio of adsorption and reaction cycles on structural, surface areas and electrochemical properties of NiO/MWCNTs nanohybrids. X-ray diffraction measurements confirm the hybridization and face centered cubic (FCC) crystal structure of NiO in NiO/MWCNTs nanohybrids. In addition, these nanohybrids exhibit excellent surface properties such as uniform

surface morphology, good surface area, pore volume, and uniform pore size distribution. The electrochemical tests demonstrate the highest specific capacitance of 1727 F g−1 at 5 mA cm−2 of current density with 91% capacitance retention after 2000 cycles. In addition, the Ragone plot confirms the better power and energy densities for all NiO/MWCNTs nanohybrids.

Recentaly A.V.Mohalkar and Colleagues studied that the Nickel oxide (NiO) powder has been fabricated by using a simple hydrothermal method. The effect of different electrolytes Na2SO4 and KOH as on supercapacitor properties has been investigated. The EDAX spectrum used for finding composition of the elements. The BET analysis used for finding surface area and pore radius of NiO powder. The surface wettability study showed that contact angle was hydrophilic in nature. In KOH electrolyte NiO–carbon cloth electrode showed better performance, NiO electrode exhibited high specific capacitances (SC) 132 Fg-1 in KOH and 79 Fg-1 in Na2SO4 electrolytes at the scan rate 5 mVs-1 with good cycling stability (~75 % retention after 500 cycles) in a KOH electrolyte [6].

The effect of cobalt doping on structural, morphological and optical properties was investigated. XRD studies reveal that all the films are polycrystalline with cubic structure and exhibit (1 1 1) and (2 2 2) preferential orientations. Co is well incorporated in the host lattice without altering the structure. All films retain high transparency throughout the visible spectral regime. No significant shift in Raman spectra was observed due to the Co doping [7].

Doping is a fundamental technique to control the properties of semiconductors and to obtain new multifunctional technological materials. Cobalt and other transition metal elements have become a focus for many researchers [8].

N.A. Mala et al. studied that the optical, magnetic, and supercapacitor properties of NPs were investigated via ultraviolet–visible absorption, vibrating sample magnetometer (VSM), and cyclic voltammetry (CV). The effect of Fe doping on the optical bandgap of NiO nanoparticles demonstrates that the bandgap increases with increasing doping concentration (x = 0.02 M, 0.04 M, and 0.06 M). The VSM exhibits ferromagnetic behavior at room temperature. Fe doped sample shows promising supercapacitor electrode material properties ensuring that NiO: Fe could act as an enhanced working electrode for the future generation of supercapacitors [9].

P.E.Saranya reported that, the field emission scanning electron microscopic analysis (FESEM) explored the transformation in morphology from pristine NiO nanosheets to 3D flower-like nanostructure of Ce doped NiO nanoflakes. Further, BET analysis revealed that surface area of NiO nanoflakes increased with Ce dopant concentration. Ce-1% flower-like nanostructure showed the larger surface area of 226.6 m2/g with an average pore volume of 1.41 cm3/g. As expected, among the five electrodes Ce-1% exhibited the maximum surface redox activity and offered a high specific capacitance of 2444 F/g at 5 mV/s scan rate which is triple the times of pure NiO nanosheets. The charge-discharge analysis resulted in a maximum specific capacitance of 1725 F/g at 1 A/g current density for Ce-1% doped NiO nanoflakes. Electrochemical impedance spectra showed a very low resistance of 1.5 Ω for Ce-1% doped NiO [10].

The morphology of the 1D NiO nanostructures is controlled by the time of annealing at 450°C. After 25 min of annealing, the NTs start to close but maintain the tubular structure, and after a further 300 min of annealing time, the tubes are completely closed and nanorods (NRs) are formed. Farrukh Iqbal Dar et al. shows that the structures obtained are highly promising for supercapacitor applications; the performance of the NiO NT structure is with a specific capacitance of 2,093 F/g, the highest ever obtained for NiO, approaching the theoretical capacitance of this material. A suitable combination of nanocrystalline grain size and the high surface area akin to the tubular structure is responsible for this high performance. In contrast, the NiO NR structure is characterized by lower performance (797 F/g) [11].

Jinping Chen and colleagues studied that, Al-doped NiO nanosheet arrays were fabricated using a facile and effective strategy for constructing an ASC. They exhibited superior discharge capacitance (2253+105 Fg^{-1} at 1 Ag^{-1}), rate capability (approx. 75% capacitance retention at 20 Ag^{-1}) and cycling stability (approx. 99% retention after 5000 cycles), much improved compared to those of undoped NiO [12].

Fan et al. reported a strategy synthesis of NiO foams on nickel foam substrates, which can greatly improve the areal performance of battery-type supercapacitors [13].

S. Sivakumar, Nazir Ahmad Mala synthesized, bare NiO and Mn2+ doped NiO NPs were by the chemical precipitation method and are calcinated at 800^0C. XRD confirms the face-centered cubic structure (FCC) of Mn2+ doped on a NiO host. The mean crystallite size of bare

NiO NPs shown a decreasing trend after doping (0.02 M%) Mn2+ concentration on NiO NPs. FTIR spectrum confirms the peak position of the stretching mode vibration of nickel, oxygen (Ni–O) band. Bare NiO NPs illustrate a maximum specific capacitance of 555 at 10mV/s. After the Mn2+ doped NiO electrode, the specific capacitance values reducing, from 555 to 319 Fg^{-1}, due to the incorporation of Mn2+ ions [14].

Gopalakrishnan Srikesh and Arputharaj Samson Nesaraj reported that, the XRD peaks of all the materials were indexed to the face-centred cubic (FCC) crystalline structure. FTIR spectra revealed the presence of NiO bending vibration mode between 432.07 to 492.83 cm^{-1}. Particle size patterns and SEM photographs confirmed the presence of nanosized grains apart from few bigger sized grains. The diameter of grains was mostly found to be in the range of 30.04 to 591.16 nm. Presence of appropriate composition of elements was confirmed by EDAX data. Polycrystalline behaviour of $Ni_{0.95}Mn_{0.05}O_{1-\delta}$ was exhibited by HRTEM data. The electrochemical phenomena of $Ni_{1-x}Mn_xO_{1-\delta}$ were studied by cyclic voltammetry (CV), galvanostatic charge – discharge and electrochemical impedance measurements in 6 M KOH aqueous solution. Among the samples studied, $Ni_{0.95}Mn_{0.05}O_{1-\delta}$ electrode exhibited maximum specific capacitance of 369.6 Fg^{-1} at a current density of 0.5 Ag^{-1}. From the characterization data, Mn-doped NiO nanostructures appear to be the good electrode materials for electrochemical supercapacitor applications [15].

T. Taşköprüa et al. Studied that the effect of cobalt doping on structural, morphological and optical properties was investigated. XRD studies reveal that all the films are polycrystalline with cubic structure and exhibit (1 1 1) and (2 2 2) preferential orientations. Co is well incorporated in the host lattice without altering the structure. All films retain high transparency throughout the visible spectral regime. No significant shift in Raman spectra was observed due to the Co doping [16].

Kate et al. reported that, the effect of Co doping on the microstructure and electrochemical performance of NiO thin film electrodes are thoroughly investigated by X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), cyclic voltammetry (CV) and chronopotentiometry. The X-ray diffraction result associated with the polycrystalline cubic structure of sprayed films with (111) as preferential orientation.The XPS analysis shows that presence of Co in NiO thin films and field emission scanning electron microscopy (FE-SEM) of 4% Co:NiO thin films showed porous surface morphology.The electrochemical results suggest

that at 4% Co doping in NiO electrodes exhibits the highest specific capacitance. The maximum specific capacitance 835 F. g^{-1} is attained at scan rate of 5 mV s-1from cyclic voltammetry in 2M KOH electrolyte. The thin film 4% Co doped NiO showed maximum specific capacitance of 246.80 F.g-1 at current density of 0.2 mA/cm^2 with 96% capacity retention after 1000 cycle. The archived results suggested Co doped NiO thin films with high performance may be use as a promising material for electrochemical supercapacitors [17].

Yuan et al. investigated that the influence of Cu doping on the electrochemical properties of NiO regarding its performance as electrodes in aqueous supercapacitors. NiO and $Ni_{1-x}Cu_xO$ (x¼0.5–3%) cathode materials were synthesized via a citrate-gel process. $Ni_{1-x}Cu_xO$ samples have the same crystal structures as those of the un-doped NiO, indicating that copper atoms enter into the lattice of nickel mono-oxide. Compared to NiO, Cu-doping materials significantly improve the specific capacitance and rate capability. Especially, among all of the investigated samples, $Ni_{0.99}Cu_{0.01}O$ presents the best electrochemical performance as high as 559 and 389 Fg^{-1}, which are 90.14% and 86.12% higher than those of NiO at 0.3 and 10 A/g, respectively. This work demonstrated that Cu-doping is an effective way to improve the pseudo-capacitance of nickel monoxide [18].

K. Sathishkumar and colleagues studied that, the nanocrystals of NiO and NiO doped with different levels of Cu2+ ions by a simple chemical precipitation method. The XRD results suggest that the doping limit of Cu2+ into NiO matrix as 0.025 M. The rod like morphology of the doped product was analyzed by SEM and confirmed by FE-TEM analysis. The paramagnetic behavior of NiO has been changed into ferromagnetic on all concentrations of doping which is resulted from the synergistic effect of smaller particle size and impurity phase formation. At low scan rate, the super capacitance performance of the NiO has been increased from 318 to 376 F/g on 0.025 M of doping. However, further increase in Cu2+ doping decreases the specific capacitance of NiO due to the formation of impurity phase. The improved supercapacitance performance of NiO with Cu2+ doping through simple preparation process renders NiO a promising electrode for practical application in supercapacitors [19].

3. Objectives of Research / proposed Hypothesis:

- To study growth of metal oxides such as undoped NiO, Co & Cu doped NiO in thin film form.
- To increase the surface area of active electrodes and hence to enhance the charge storing capacity of undoped NiO, Co & Cu doped NiO.
- To characterize undoped NiO, Co & Cu doped NiO thin films for structural, morphological, compositional and electrical properties.
- To study electrochemical properties such as cyclic voltammetry and galvanostatic charge/discharge of undoped NiO, Co & Cu doped NiO thin film based supercapacitors.
- To study the effect of dopant on the properties of undoped NiO, Co & Cu doped NiO thin films on the supercapacitive and gas sensing performance.

4. Methodology to be adopted:

There are various thin film deposition techniques available for deposition of thin films. Among these various deposition techniques available for preparation of thin films, the successive ionic layer adsorption and reaction (SILAR) Technique.

These SILAR methods is a solution-based techniques, it is widely used for the synthesis of the various type of metal oxide/hydroxide thin films, these techniques more commonly used to preparations of the different type nanostructured materials. SILAR is a simple, cost effective, binder free method and it is appropriate method for synthesis of large-scale of nanostructure materials. The successive ionic layer adsorption and reaction (SILAR) Technique will be used to grow undoped and doped NiO thin films. The work will performed in following manner:

a) Growth of Good Quality NiO Thin Films.

It is proposed to grow undoped NiO, Co & Cu doped NiO thin films by successive ionic layer adsorption and reaction (SILAR) Technique. At initial stages the efforts will be done in order to deposit good quality undoped NiO, Co & Cu doped NiO thin films on glass and steel substrates. The various preparative parameters like concentration of precursor solution, thickness, substrate temperature and other parameters will be optimized to get good quality undoped NiO, Co & Cu doped NiO thin films. The as deposited films will be characterized by various characterization techniques.

b) Structural Studies:

The as deposited undoped NiO, Co & Cu doped NiO thin films will be characterized by X-Ray diffraction (XRD) technique. The crystal structure, interplanar spacing, lattice planes, lattice parameters and crystallite size will be obtained and correlated with the film properties.

c) Morphological and Compositional Studies:

The morphology of the prepared undoped NiO, Co and Cu doped NiO thin films will be studied by using Scanning Electron Microscopy (SEM) or Atomic Force Microscopy (AFM). The grain size, surface roughness, porosity will be studied using SEM and AFM techniques. The compositional analysis of as deposited undoped NiO, Co and Cu doped NiO thin films will be studied by using Energy Dispersive Analysis by X–Rays (EDAX) technique. The correlation between as taken composition and film composition will be obtained.

d) Optical Studies:

The optical absorption of undoped NiO, Co and Cu doped NiO thin films will be obtained by using UV–Vis (Ultraviolet–Visible) spectrophotometer. The coefficient of absorption, band gap energy (Eg), nature of transition, power factor will be obtained from optical absorption spectra.

e) Electrical Studies:

The electrical resistivity measurements of as deposited undoped NiO, Co and Cu doped NiO thin films will be carried out by using DC two point probe method. The room temperature conductivity, activation energy will be obtained and correlated with film properties.

f) Electrochemical Supercapacitor Studies:

Performance of undoped NiO, Co and Cu doped NiO thin films in supercapacitor will be evaluated with respect to various parameters such as scan rate, specific capacitance, stability cycles and potential range. The supercapacitive performance of undoped NiO, Co & Cu doped NiO thin films will be tested for symmetric and asymmetric modes, for achieving high power density. The galvanostatic charge-discharge mechanism will be studied using chronopotentiometry and the parameters such as specific capacitance, coulomb efficiency, specific energy, and specific power will be calculated. The electrochemical impedance spectroscopy analysis will be carried out in order to find the Rs and Rct values.

g) Effect of technical parameter:

To study the effect of technical parameter the films will be doped with traces of impurity and will be studied for all above mentioned characteristics.

The purpose of research work is to improve pseudo-capacitive properties such as specific power, specific energy and coulomb efficiency of undoped NiO, Co & Cu doped NiO thin films by using simple and cost effective successive ionic layer adsorption and reaction (SILAR) Technique.

5. Importance of Study/Society Application:

A modern technological society demands the use and storage of energy on a major scale, employing large and small system for that purpose. The energy stored in the capacitor is non faradaic electrical energy. No chemical changes are involved and hence cycle life of capacitor is unlimited. Super capacitors are maintenance free. Now a day's electrochemical capacitors or supercapacitors are used as storage devices to complement batteries. Supercapacitor have attracted more and more attention because of their advantages such as fast charging and discharging, long life span, simple principle and high power density compared with lithium batteries and traditional dielectric capacitors. Supercapacitors are used in particular, cars and trains, light weight electronic fuse, backup power sources for calculators, portable electronic devices, foldable electronic devices and wearable mobile phones.

6. Chapter Scheme:

Chapter I: Introduction

Chapter II: Thin Film deposition and Characterization Method

Chapter III: Preparation and Characterization of undoped NiO, Co & Cu doped NiO thin films

Chapter IV: Applications of undoped NiO, Co & Cu doped NiO thin films for Supercapacitor and Gas sensing

Chapter V : Summery, Conclusions and Future Scope of the present work

7. Proposed Work Plan:

Year wise plan of work and target to be achieved:

Plan of Work and Target to be achieved during First Year:

During the first year competition of Research course work, all chemicals will be procured. A through literature survey will be done in order get good knowledge of metal oxides for supercapacitors and gas sensing applications. Efforts will be done in order to deposit good quality undoped NiO and Co & Cu doped NiO thin films by using successive ionic layer adsorption and reaction (SILAR) Technique. Various preparative parameters will be optimized.

Plan of Work and Target to be achieved during Second Year:

In second year the undoped NiO and Co & Cu doped NiO thin films will be characterized by various techniques such as XRD, SEM, FESEM, AFM, TEM and EDAX, in order to study the structural, morphological and compositional properties. The films will be studied for optical properties using UV-Vis spectrophotometer. The as grown films will be characterized by electrical resistivity measurement. Performance of undoped NiO and Co & Cu doped NiO thin films in supercapacitor will be evaluated with respect to various parameters such as scan rate, specific capacitance, stability cycles and potential range. The results obtained will be discussed and interpreted. At least two progress reports will be sent during the year. Two research papers will be communicated to the reputed journal at the end of this year.

Plan of Work and Target to be achieved during Third Year:

Results obtained in second year will be analyzed and published in reputed journals. Also the outcomes of our research work will be presented in national and international gatherings such as Seminars, Workshops, and Conferences set during this year. Once this is done final synopsis will be submitted and after this thesis will be written. Thesis will be submitted to the university.

8. References:

[1] M. Winter, R.J. Brodd, What are batteries, fuel cells, and supercapacitors? Chem. Rev.104 (2004) 4245-4270.

[2] B.E. Conway, Electrochemical Supercapacitors: Scientificand Technological applications, kluwer, (Nework) 1999.

[3] Yunus Akaltun, Tuba Çayır, Fabrication and characterization of NiO thin films prepared by SILAR method, Journal of Alloys and Compounds 625,144–148 (2015).

[4] Mahima Ranjan Das, Atanu Roy, Siyasanga Mpelane, Ayan Mukherjee, Partha Mitra,

Sachindranath Das, Influence of dipping cycle on SILAR synthesized NiO thin film for improved electrochemical performance, Electrochimica Acta (2018).

[5] Girish S. Gund, Deepak P. Dubal, Sujata S. Shinde, and Chandrakant D. Lokhande*, Architectured Morphologies of Chemically Prepared NiO/MWCNTs Nanohybrid Thin Films for High Performance Supercapacitors, ACS Applied Materials & Interfaces 6 (2014),3176−3188.

[6] S.D. Dhas, P.S. Maldar, M.D. Patil, A.B. Nagare, M.R. Waikar, R.G. Sonkawade, A.V. Moholkar, Synthesis of NiO nanoparticles for supercapacitor application as an efficient electrode material, Vacuum, 2020.

[7] T. Taşköprü, F. Bayansal, B. Şahin and M. Zor, Structural and optical properties of Co-doped NiO films prepared by SILAR method, Philosophical Magazine, 95:1, 32-40, (2015).

[8] B. Sahin, F. Bayansal , M. Yüksel , H.A. Çetinkar, Influence of annealing to the properties of un-doped and Co-doped CdO films, Materials Science in Semiconductor Processing 18 , 135–140 (2014).

[9] Nazir Ahmad Mala, S. Sivakumar, Khalid Mujasam Batoo, Muhammad Hadi, Design and fabrication of iron-doped nickel oxide-based flexible electrode for high-performance energy storage applications, Inorganic Chemistry Communications 131 (2021) 108797.

[10] P.E.Saranya, S.Selladurai, Mesoporous 3D network Ce doped NiO nanoflakes as high performance electrodes for supercapacitor applications, New Journal of Chemistry 1-33 (2019).

[11] Farrukh Iqbal Dar, Kevin Radakishna Moonooswamy and Mohammed Es-Souni, Morphology and property control of NiO nanostructures for supercapacitor applications, Nanoscale Research Letters 2013.

[12] Jinping Chen, Xianyun Peng, Lida Song, Lihan Zhang, Xijun Liu and Jun Luo, Facile synthesis of Al-doped NiO nanosheet arrays for high-performance supercapacitors, Royal Society open science,2018.

[13] Fan Y, Ma Z, Wang L, Dong Y, Jiang T, Li Z, Liu L, Shao G., In-situ synthesis of NiO foamed sheets on Ni foam as efficient cathode of battery-type supercapacitor. Electrochim. Acta 269, 62– 69. 2018.

[14] S. Sivakumar, Nazir Ahmad Mala, Synthesis and characterization of manganese doping on NiO nanoparticles and its supercapacitor applications, Materials today: Proceedings (2021).

[15] Gopalakrishnan Srikesh, Arputharaj Samson Nesaraj, Facile preparation and characterization of novel manganese doped nickel oxide based nanostructured electrode

materials for application in electrochemical supercapacitors, Journal of Asian Ceramic Societies, 835–847, (2020).

[16] T. Taşköprüa, F. Bayansalb,, B. Şahinc and M. Zora, Structural and optical properties of Co-doped NiO films prepared by SILAR method, Philosophical Magazine, 2015 Vol. 95, No. 1, 32–40.

[17] R.S. Kate, R.J. Deokate, Enriched electrochemical properties in Co doped NiO thin films deposited by spray pyrolysis, Materials science for technologies, (2020).

[18] Guohui Yuana, Yunfu Liua, Min Yue, Hongju Li, Encheng Liu, Youyuan Huang ,Dongliang Kongc, Cu-doped NiO for aqueous asymmetric electrochemical capacitors, Ceramics International (2014).

[19] K. Sathishkumar, N. Shanmugam, N. Kannadasan ,S. Cholan , G. Viruthagiri, Synthesis and characterization of Cu2+ doped NiO electrode for supercapacitor application, J Sol-Gel Sci Technol, (2015)

Date: 25/03/2022

Place: Latur

Mr. M. B. Kumbhar
Research Scholar

Dr. P. M. Kulal
Research Supervisor